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STUDIES FOR STUDENTS

THE MAPPING OF THE CRYSTALLINE SCHISTS.

PART I.—METHODS.

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INTRODUCTION.

CONVENTIONAL GEOLOGICAL MAPS A MIXTURE OF FACT AND THEORY IN UNKNOWN PROPORTIONS.—For areas of the crystalline schists no person save the maker or some one familiar with the area represented, can form any estimate of the value of a geological map. In proportions dependent not alone upon the worker and his conditions, but upon the area itself, theory has been compounded with fact, until the map represents not what is, but what the maker thinks after a study more or less extended. Unfortunate also it is that the thoroughness and detail of the study is not revealed. It is true that a geological map may be so constructed as to disclose at once an impossible condition, or one so contrary to common experience as to excite suspicion, so that von Decken, the greatest of German map makers, once said that there were really but two classes of geological maps—those that may be right and those that cannot be right. But on the other hand, a map may be prepared with but little examination upon the ground, which is quite as plausible in aspect, or it may be even more plausible, than one prepared by a conscientious and competent worker who at great expense of labor and thought visits each exposure and studies it with respect to all its neighbors.

In regions in which rock types are easily distinguished, and where the tectonic structure is simple, the difficulties above referred to are reduced to a minimum; but in belts in which the rocks have been profoundly metamorphosed, and where orographic forces have brought about a complex structure, the dangers which arise from compounding fact and theory may be so great as to practically destroy the value of the map.

OUTCROP MAPS NEEDED TO DISPLAY THE FACT.— The largest element of danger is removed and a map increased very much in value by indicating upon the tinted areas of the different formations (the theory) the position, the nature and the observed peculiarities of the outcroppings (the fact). If a map has been made without sufficient field study this fact will then appear, and if it must be more thoroughly worked out and republished, the earlier work is not lost if it was intelligently and conscientiously done. If, however, it was carelessly, or for any reason inefficiently done, the examination of a few of the exposures which have been represented upon the map will supply the basis for judgment. In a complex area much time is consumed in making a just estimate of the value of a conventional geological map, and if revision is necessary the work must be taken up *de novo*, even if the field work was efficient so far as it was carried.

The serious objection to the general use of outcrop maps is, of course, the great expense which they involve because of the large scale which must be adopted. In the complex region bordering Lake Superior, the United States geological survey has most wisely adopted the plan of publishing outcrop maps to properly present the careful work of the geologists of the division. It is safe to say that the time is not far distant when equally precise methods must be adopted at least by government and state institutions for all regions of equal or of greater complexity.

FACT.—THE OBSERVATIONS.

ROUTINE FIELD OBSERVATIONS.—*Location of outcrops.*—The first requisite for geological mapping in a region of crystalline rocks, is an accurate base map of sufficiently large scale. Unless the relief is slight or the topography of a simple character, it is essential that the topography be represented either by hachures or contours, preferably the latter. A scale of an inch to the mile (1 : 62,500) with a contour interval of twenty feet will no more than suffice to express the detail that is necessary for the best results. If roads are numerous and reasonably good, a bicycle with cyclometer attachment will be a valuable adjunct, and with little doubt the best way of securing base locations as well as getting quickly from place to place.[1]

By the use of the aneroid and 4-inch sighting compass, and by pacing, all locations can probably be made with sufficient accuracy if the base map is reasonably good and the country is one of diversified topography. In a wilderness like that about Lake Superior, where the monotonous uniformity of the topography and the forest cover make outlook impossible, the matter of location becomes exceedingly difficult. The problem has there been solved by scouring the country for outcrops in parallel and contiguous belts, a compassman accompanying each geologist to keep the direction and pace the distance, so as to allow him some freedom of movement.

Examination of rock and collection of specimens.—The examination of the rock is made upon the ground after securing the freshly broken surface of a specimen as little weathered as possible.

The specimen should be examined with the naked eye for its general aspect and compared with the weathered surface of the outcrop. Its manner of fracturing under the hammer may be of much significance, and of two closely similar rocks it may even remain the chief distinguishing difference in the field observation. With a pocket lens of a magnification of 6–14 diameters, according to personal preference,[2] a more careful examination is made of the fresh surface to note the essential and accessory minerals and their relative proportions, the texture of the rock, the evidence of crushing, etc. A specimen of the fresh rock, in case the type is new to the region or of doubtful determination, is made by trimming a fragment into the shape of an elongated rectangular pillow three by four inches and of a maximum thickness of an inch. One or more chips for section cutting are also collected. When determinations are extremely difficult a series of smaller specimens untrimmed and showing the weathered as well as the fresh surfaces will be found far more valuable for identification and reference. These to the number of ten or more and representing as different phases as possible may be chipped from a single exposure or from near-lying exposures and given a single number as a series.

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[1] HOBBS, "The Geologist Awheel," *Pop. Sci. Month.*, Vol. LVIII, pp. 515–518.

[2] The best lenses for the purpose are the Hastings aplanatic triplets, manufactured by Bausch & Lomb, Rochester, N. Y.

Measurement of strike and dip.—It is a time-honored and almost uniform practice to record the present direction of the plane of bedding in terms of the strike (the direction of the water line if the outcrop were partially submerged) and the dip (its inclination normal to the strike). Both these terms have a definite meaning when applied to the only slightly disturbed sedimentary rocks, and may properly be measured by the text-book methods, the former by leveling the compass with its north-south edge in contact with the bedding plane and reading the bearing, the latter by taking the steepest inclination of the beds—the one normal to the strike.

In the crystalline schist areas, however, the matter is far from simple. The rock may have no definite structure plane, either because of igneous origin or from metamorphism of a bedded rock. Again it may show one or more prominent structures, but no one of them may represent the plane of sedimentation. If one of them is proven to be the plane of bedding the best determination of the strike would probably not be obtained by the text-book method of placing the compass edge in contact with the rock surface. A quicker and generally more correct method is to hold the compass above or beside the exposure and adjust it by the eye to correspond to the average strike of the exposure. The error of the eye in adjusting to parallelism, which should hardly exceed 5°, is inconsiderable when the variation between different parts of an exposure or between near-lying exposures is taken into account.

Something further will be said upon the differentiation of original and secondary structures

IMPORTANT ADDITIONAL OBSERVATIONS.—*Pitch and its measurement.*—Hardly less important than the inclination of the bedding plane at a locality is the pitch of the folds—the inclination of their trough and crest lines. Vital as is this element in the determination of the structure of an area, it is only in recent years that it has been given much weight in field investigations. It is safe to say that its importance is yet only half appreciated. To Professor Raphael Pumpelly, who directed the early field work in the New England area, is due the credit of bringing to the front this element in the field study of crystalline rocks. The details regarding the methods of measuring it were worked out by the assistants in his division.[1]

The pitch is often consciously or unconsciously measured as a component element of the dip, the dip being increasingly determined by the pitch as the outcrop is near the crest or the trough of a fold. Pitch can only be measured at the locality when the outcrop exhibits minor folds or plications, the study of the Green Mountains having clearly demonstrated the fact that the minor fold is the epitome of the major fold. The pitch is subject to the same kind of variations within an exposure as is the dip, and it must not be recorded from a single minor fold or plication without first noting whether other folds or plications give similar values. Even then its inclination cannot fairly be assumed beyond the exposure itself, and it is only by examination of a series of exposures that a *persistent pitch* is determined.

When not to be made out at an exposure, pitch (and here a persistent one) is correctly inferred when the strikes of the opposite limbs of a fold are other than parallel. A syncline pitches in the direction in which the strikes of its opposite limbs diverge and an anticline in the direction in which they converge.

Inferences regarding the pitch may often be drawn from the profiles of ridges, the gradually sloping lines being formed by the crests of folds.

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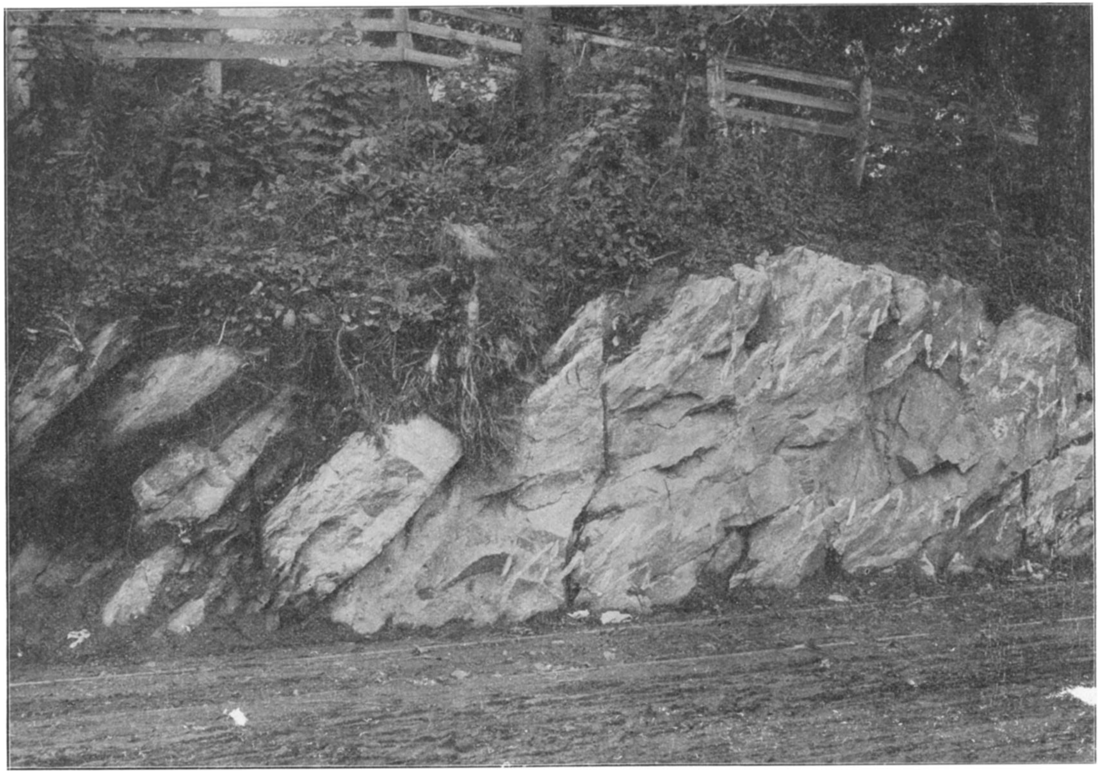
[1] See *Monograph XXIII, U. S. Geol. Surv.;* also VAN HISE, "Principles of Pre-Cambrian Geology," *Sixteenth Ann. Report U. S. Geol. Surv.*, Part I, 1896, pp. 603–632.

Plate I.



SECONDARY FOLIATION AND BANDING IN GNEISS ON STATE ROAD NEAR GREAT BARRINGTON, MASS.

The direction of the original plane of bedding is now nearly horizontal as indicated by the lines of crumpled quartz lenses near the top and bottom of the exposure. The secondary foliation and banding appear at the left and between the crumpled rows of quartz lenses.

Van Hise has shown that the crests of folds are lines of special importance by reason of the fact that the order of superposition of beds is there almost sure to be the normal one, and the additional fact that crushing being there at a minimum, conglomeratic and other original structures are most likely to be preserved.

Form of minor folds.— As might be inferred from the last section, the form of the minor fold or the plication is full of meaning respecting the characteristics of the larger folds of the region, and it should, therefore, be carefully studied and its peculiarities sketched or recorded.

Secondary foliation and its relation to bedding.— Foliation is one of the commonest of the structures in the crystalline schists. It is now well known that in the recent past the strike and dip of foliation have rather generally been measured as those of bedding, so that in most papers, written more than a decade since, the secondary nature of foliation was not recognized, and recorded observations of dip and strike as frequently refer to secondary foliation as to planes of sedimentation. Even with the larger knowledge of the present, the differentiation of the two structures is difficult and often impossible. Two, three, or even more sets of planes of separation, with widely different directions, may all be easily made out in the same hand specimen of clastic rock, and yet no one of them correspond in direction with the bedding plane.

A difference in composition characterizing alternate parallel bands of considerable thickness is undoubtedly the best criterion for determining the plane of sedimentation.[1] A striking instance of secondary banding is represented in Plate I, where the bedding plane is outlined by the crumpled lenses of quartz and by even more beautiful puckered bandings not discernible in the view. The secondary straight banding is parallel to the foliation. (Plate XIV of the work last cited is from near this locality.) Such a structure, or one resembling it, may, however, be produced by the mashing of a coarse granite or conglomerate, but the characteristic structures of these rocks are usually not obliterated unless the bands are reduced to a thickness of a quarter of an inch or less. Again injection of granitic material along the planes of foliation of a rock may produce an alternation of bands of different composition. Such a structure is, however, apt to be recognized by an experienced observer, and unless subsequently mashed the bands are not sufficiently uniform in thickness to simulate bedding.

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[1] See, however, HOBBS, "Secondary Banding in Gneiss," *Bull. Geol. Soc. Am.*, Vol. III, pp. 460–464, Pl. XIV.

Of all the crystalline rock types of clastic origin, quartzite offers the greatest difficulties in the search for the bedding plane. In fact, it is generally impossible to determine it except by contacts with other formations.

Other things being equal, the more crenulated or wavy a structure, the greater the probability that it is original. Also the more its general direction diverges from an undisturbed plane of foliation the more likelihood is there that it is earlier and original. When the bedding plane cannot be made out with certainty at a particular locality it may sometimes be inferred from a study of the form of the minor folds in their relation to foliation at a neighboring locality. Owing to the fact that mashing is at a minimum in the arches of folds, careful search in an area of closely compressed folding will often reveal at regular intervals the beautifully crenulated arches with foliation planes bisecting them, although between such localities the foliation planes only can be found. Such a method may even be applied to a slate. The green and purple slates of the Taconic range of mountains dip to the eastward persistently and quite uniformly. The writer was able to find at fairly regular intervals across the strike of this foliation the acute crests of easterly dipping anticlines preserved in lenses of infiltrated silica, thus showing that a series of moderate thickness has, by buckling and compression, brought about perfect foliation parallel to the axial planes of the folds, and thus given the impression of vast thickness.

Van Hise, in his treatment of the mechanics of flexuring — confirmed by field observation — has shown that in moderately compressed folds the foliation planes of the opposite limbs converge downward in an anticline and upward in a syncline.[1]

Joint planes.—Joint planes more or less perfectly developed are almost universally present in the crystalline rocks. They are planes of separation in parallel series, of which more than one is usually to be made out. They usually have a very steep inclination and are probably like the folding, in most cases a result of the compression of the area. Their number (*i. e.*, the number of series) and relative perfection, and the direction and inclination of their walls, should be carefully noted, with the relation of these to lines of displacement and to topographic features.

Scarps and steep rock walls.—Little attention seems to have been accorded these features of rock exposures. In the sequel I propose to show their importance in the geological structure of a region. Their direction and magnitude should be noted, and if possible some symbol easily distinguished from the dip and strike symbol should be entered at least upon the working map. A short dotted line will serve to indicate the direction of the scarps and a figure at its end its bearing to the east or west of north.

Margin of outcrop.—Another neglected feature of rock exposures is the margin of the outcropping. Every experienced geologist must be able to recall numerous instances where outcrops, grouped so thickly as to indicate probably but slight covering in the intervening area, cease abruptly at a border which is often nearly or quite rectilinear and perhaps is also for sections of its extension the margin of individual exposures. Such observations, it is believed, are of great significance in the proper interpretation of the structure of a region.

Gorges and sharp straight valleys.—Even the best of the topographical maps do not indicate all gorges or rectilinear valleys with rock walls. In the interpretation of the geological structure their significance may be considerable, and it is important to note their direction and in many cases also the height of their walls. A symbol like the cut will be found useful in recording them upon the map. The figure at the end of the trough line of the valley indicates the bearing in degrees to the east or west of north, as the case may be. The slope lines on either side pointed toward the trough are like Dana's dip symbols adjusted in length to indicate the steepness of the slope, a large slope line indicating a gentler slope. The figures used in connection with these lines indicate the height in feet of the walls on either side, an estimate being expressed by the ± sign. Very large and important valleys are often omitted from topographic maps the topography of which is sketched, because hidden from points at which the sketches were taken.

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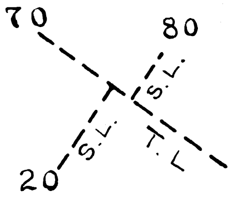
[1] See on the general subject of foliation, PUMPELLY, WOLFF and DALE, *Monograph* XXIII; *U. S. Geol. Surv.*, pp. 136–158, Pt. I, 1896; and VAN HISE, *Sixteenth Ann. Report U. S. Geol. Surv.*, Pt. I, pp. 633–668.



Nature of contact surface of formations.—Contacts of formations wherever exposed should be carefully scrutinized, not only to discover evidence of conformity or unconformity, but for indication of slipping, thrusting or faulting. The contact plane of formations for two reasons is likely to be a locus of displacement. In the first place contacts are likely to be planes of weakness where a maximum of movement has occurred ; and in the second place, displacement, whether by normal faulting or thrusting, produces new contacts. It is, therefore, to be noted at the contact of sedimentary formations : first, whether the plane of contact is the natural result of sedimentation, and whether conformable or not; second, whether the deformation of the contact plane, if present, is such as may be explained by accommodation of layers in flexuring, or must be accounted for by the more violent processes of normal faulting or thrust. With good exposures the direction of the plane of displacement will probably allow of a decision between thrusting and normal faulting. If insufficiently exposed the nature of the folding and the general character of the deformation within the area may afford a clue. Both normal faulting and thrusting may, however, have occurred at the same contact.

THEORY.—THE DRAWING OF BOUNDARIES AND COLORING OF MAP.

THE CANONS OF GEOLOGICAL MAPPING FOR THE CRYSTALLINE AREAS. —The determination of what types of rock shall be grouped under one formation-color may be a problem of the greatest difficulty, but in the absence of conglomerates or clearly marked unconformities, the question is a petrological one to be settled by the best judgment of the observer on the ground checked by subsequent microsopical and perhaps chemical investigation in the laboratory. Where the contacts are not sharp but exhibit gradational facies, there may be a question as to where the dividing surface should be fixed, but this is after all a matter of comparatively small moment, and however determined, there is little danger that much violence will be done the facts.

The drawing of boundaries where contacts are not exposed—and contacts are generally covered—is a problem calling not only for much judgment but often also for a large imagination. In most domains of science the worker is allowed to express his lack of adequate data upon which to base a conclusion, and to reserve his judgment pending the obtaining of fuller information. Here, however, the demand is peremptory and the line must be drawn with or without knowledge. It is no uncommon experience to find within a region of intricate geological structure an alluvial valley a mile or more in width bordered by drift mantles of only lesser width before the bed rock is exposed. However the boundary lines of the formations are drawn, the map maker may be reasonably sure of one fact only, —that the reality is totally different from the representation. Convention requires that all areas shall be colored to show the underlying rock, and it may at least be said that the result is every whit as attractive and plausible in appearance as though the coloring were based throughout upon observed facts.

It is perhaps a step in the right direction to leave the lakes and rivers uncolored, as is now done by the United States geological survey upon its atlas sheets; but to this also there are serious objections, as, for example, in the area about New York city, where the numerous bridges, piers and abutments, tunnels, and government dredgings afford a body of knowledge of the submarine bed rock equal to that obtainable from most land areas.

The necessity for drawing boundaries in covered areas has evolved a body of largely unwritten doctrine which may not inaptly be referred to as the canons of geological mapping for the crystalline areas. Some of these canons are truths, others half truths, and still others have little basis in fact. Some of the more important of them are subjoined with brief critical notes. They are of course to be weighed in connection with one another and a compromise decided upon.

1. *Propinquity of outcrop.— Near-lying outcrops should be connected when not separated by outcrops of a different formation.* This rule is almost axiomatic and thoroughly sound in principle provided no contrary evidence is at hand; but there is yet a possibility of error even when outcrops are separated by less than one hundred feet.

2. *Contacts covered.— The boundary is not at the margin of either of the separated outcrops of different formations, but at some line between.* This is a general rule but with many exceptions.

3. *Strike.—Direction of boundary conforms to strike of near outcrops.* A rule of much value but to be weighed with other considerations before decision is made.

4. *Slopes.— On slopes boundaries should be corrected for strike and dip.* With vertical beds if the strike is away from the elevation in the general direction in which the boundary is being extended, the boundary will run down the slope, if toward the elevation it will run up the slope. If the slope also changes in such manner that the contour line converges less or diverges more from the strike the boundary will curve more rapidly down the slope; if the contours diverge less from or converge more with the strike in that same direction, the boundaries will the more rapidly ascend the slope. If the dip is with the elevation the boundary bends the more up the slope, if out from the elevation the more down the slope.

5. *Topographic breaks.— Sudden changes in slope not caused by talus or drift are likely to correspond to contacts.*

6. *Variable hardness of rock.— Ridges are occupied by harder rock, valleys by softer or more soluble rock.* To be applied with great caution. In many districts, in the opinion of the writer, the valleys are nearly if not quite as often hard as soft rock. A structural line of weakness may have produced a pre-glacial stream bed which the ice-cap widened and deepened; an antecedent stream may have produced the same result in hard rocks, an orographic block may have suffered depression, etc.

7. *Hydrography.—In a limestone and hard rock country lakes, ponds, rivers, and swamps are generally in softer or more soluble rock.* A most pernicious doctrine because so generally accepted and so frequently wrong. Faith in the canon also discourages investigation. The writer has in mind a nearly circular lake in the middle of a great valley largely underlaid by limestone, but about one-half the lake bottom is mica schist, the other half limestone.

8. *Ridge and valley structure.— Ridges are more generally synclines and valleys anticlines.* A half truth. It is perhaps true in the greater number of instances of rocks which suffer an amount of plication and rupturing of flexures (schists, slates, and sometimes limestones). It is not true of the heavy gneisses which so generally raise their heads in domes, the beds quite generally dipping with the slopes.

9. *Blocks.— Angular blocks when not lying on steep slopes and not clearly ice borne are on bed rock of the same kind.* The tendency is to drive this doctrine to its limit. For great limestone blocks not strengthened by silica or silicates it may perhaps be assumed that they are not very far from the parent ledge. With a framework of silica they have been carried by the ice thirty miles or more.

10. *Sink-hole structure.— Superficially undrained areas when not morainal (or in drift) are on limestone.* A pretty safe rule.

11. *Soil.—In a limestone and hard rock country arable farm land is on limestone and woodland on hard rock.* A fairly useful rule if applied intelligently.

CANONS OF MAPPING MODIFIED BY BASAL ASSUMPTIONS.—The above canons are to be considered in connection with one another, the worker giving to each what weight in his judgment is best to secure a compromise for the result. They are perhaps as good a set of rules as we can secure for the settlement of matters regarding which the known facts are insufficient to allow of a definitive conclusion.

A map constructed upon observations and rules as above outlined might be difficult to read, as the order of superposition of the formations might not at once be clear. The formations do not always appear upon the map in their direct order, being sometimes inverted, and sometimes individual formations do not lie next to their immediate neighbors above and below. The map maker is expected to show how each formation has been brought into its present positions and attitudes, to do which fundamental assumptions of far-reaching importance are made Theory is thereby brought in very large measure into the solution of the problem, it may be so as to take precedence over the canons of doctrine which have been outlined above. These basal assumptions and their effect upon the map will be considered in a second paper.

WILLIAM HERBERT HOBBS.